USAARL Report No. 2011-21

Motion Sickness Prevention by 8 Hz Stroboscopic Environment during Actual Air Transport

By Catherine Webb
Arthur Estrada
Jeremy Athy
Melody King

United States Army Aeromedical Research Laboratory

Warfighter Health Division

September 2011

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), 8725 John J. Kingman Road, Suite 0944, Fort Belvoir, Virginia 22060-6218. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about Laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Human Use

Human subjects participated in this study after giving their free and informed voluntary consent. Investigators adhered to Army Regulation 70-25 and USAMRMC Regulation 70-25 on use of volunteers in research.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
27-09-2011	Final	

4. TITLE AND SUBTITLE

Motion Sickness Prevention by 8 Hz Stroboscopic Environment during Actual Air Transport

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Catherine M. Webb
Arthur Estrada
Jeremy R. Athy
Melody R. King

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, AL 36362

8. PERFORMING ORGANIZATION REPORT NUMBER

USAARL 2011-21

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Medical Research and Materiel Command Telemedicine and Advanced Technology Research Center AMEDD Advanced Medical Technology Initiative
Bldg 1056
Patchel Street
Fort Detrick, MD 21702-5012

10. SPONSOR/MONITOR'S ACRONYM(S)

MRMC-TT

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Previous research has shown that retinal slip can be a significant factor in causing motion sickness. Stroboscopic illumination is believed to prevent retinal slip by providing snapshots of the visual environment that are brief enough so each image is stationary on the retina. The purpose of this study was to determine the effectiveness of an 8 Hz stroboscopic environment as a motion sickness countermeasure during a nauseogenic flight in a helicopter. The study population was comprised of 20 motion sickness susceptible participants. Participants completed a motion sickness symptom questionnaire, cognitive tasks, reaction time tests, and weapons utilization tasks after nauseogenic flights with and without 8 Hz stroboscopic illumination in the cabin. Results indicate that self-reported nausea scores were significantly reduced in the stroboscopic condition. Also, there was a significantly greater performance decline over the course of the reaction time task in the non-stroboscopic condition. These results support the use of stroboscopic illumination as a non-pharmacologic countermeasure for motion sickness related to retinal slip.

15. SUBJECT TERMS

motion sickness, stroboscopic, airsickness, retinal slip

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Loraine St. Onge, PhD
UNCLAS	UNCLAS	UNCLAS	SAR	45	19b. TELEPHONE NUMBER *(Include area code)* 334-255-6906

Reset

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Acknowledgements

The authors would like to express their sincere gratitude to the following people for their contributions to this project:

- LTC Steve Gaydos and Lt Col Lynne Walters for their medical support.
- SGT Brad Wilson and SPC Dale Cmaylo for their roles as ombudsmen.
- Mr. Victor Estes, Mr. Kevin Baugher, and Mr. Jeff Holemo for their technical expertise.
- Mr. Andrew Lantz for graphic design.
- SGT David Allen, SSG Craig Berlin, Mr. Jim Chiaramonte, SGT Pedro Cruz, Mr. Bradley Erickson, SSG David Lopez, Ms. Lana Milam, Ms. Edna Rath, and Ms. Melinda Vasbinder for their help with data collection.
- DAC John Ramiccio, CPT Nick Spangler, CPT M. Chris Wingate, and CPT Michael Crivello for their support as research aviators.
- Ms. Diana Hemphill and Ms. Jean Southwell for assistance with literature searches and reviews.
- Ms. Elizabeth Stokes for help with administrative matters.
- Dr. Loraine St. Onge and Ms. Deahndra Grigley for editorial support.
- Dr. Heber Jones for help with the marksmanship data.

Table of contents

Page

Introduction 1

Treatment of motion sickness 1

Flicker vertigo and photosensitive epilepsy 3

Military relevance 4

Research objectives 4

Methods 4

Research design 4

Subjects 4

Equipment 5

Dependent measures 7

Motion Sickness Questionnaire 7

Psychomotor Vigilance Task 8

Engagement Skills Trainer 2000 9

Time estimation task 10

Rapid Visual Information Processing 11

Procedure 12

Results 13

Demographic data 13

MSQ data 13

PVT data 15

EST data 17

Prone supported 17

Table of contents (continued)

Page

Prone unsupported 18

Kneeling 20

Time estimation data 22

RVP data 23

Discussion 24

Limitations 25

Conclusions 26

References 27

Appendix A. Motion Sickness Susceptibility Questionnaire 32

Appendix B. Flight profile 33

Appendix C. Motion Sickness Questionnaire 34

Appendix D. Order of assessment battery 35

Appendix E. MSQ frequency data. 36

Appendix F. Pairwise comparisons for EST data 37

List of figures

1. Flight profile……...…….6

2. Schematic of strobe placement in aircraft……..……..6

3. Hand-held PVT device……..……..8

4. Engagement Skills Trainer 2000 set-up……..…….9

5. Screen capture of aiming trace to determine root mean square…….10

6. Screen capture of time wall task……...….11

7. Screen capture of the RVP task……...…..11

Table of contents (continued)

List of figures

Page

8. Mean ± SE MSQ scores by lighting condition……..14

9. Mean ± SE PVT reaction time data by lighting condition……..…15

10. Mean ± SE PVT lapse data by lighting condition……16

11. Mean ± SE PVT RRT slope data by lighting condition…….……..16

12. Mean ± SE EST prone supported data by lighting condition and target distance……....18

13. Mean ± SE EST prone unsupported data by lighting condition and target distance……..…..20

14. Mean ± SE EST kneeling data by lighting condition and target distance……22

15. Mean ± SE Time estimation accuracy data by lighting condition……...23

16. Mean ± SE RVP A' data by lighting condition……...……24

List of tables

1. Results of paired samples *t*-test for MSQ data……...…14

2. Results of paired samples *t*-test for PVT data……16

3. Results of repeated measures ANOVA for prone supported rifle marksmanship……..…17

4. Results of repeated measures ANOVA for prone unsupported rifle marksmanship…….……19

5. Results of repeated measures ANOVA for kneeling rifle marksmanship…….21

Introduction

Dizziness, nausea, vomiting, drowsiness, pallor, sweating, and overall malaise that are triggered by travel in a boat, car, train, or plane all fall into the category of motion sickness (Lawther & Griffin, 1988; Griffin & Mills, 2002a, 2002b; Howarth & Griffin, 2003). Motion sickness has been well known for thousands of years. Ancient seafaring nations were very familiar with this malady. This problem has become increasingly prevalent in the modern world with the development of many forms of vehicular travel. The syndrome appears to arise from a disturbance in the vestibular apparatus, organs used to maintain balance and sense orientation and movement. The most widely accepted theory concerning the cause of motion sickness focuses on sensory mismatch between the visual and vestibular systems (Eyeson-Annan, Peterken, Brown, & Atchison, 1996). For example, passengers on cruise ships are far more likely to get seasick when below deck because their vestibular apparatus detects motion while their visual system does not (Gordon et al., 1994). Standard advice for such seasickness is to go up on deck where vestibular and visual inputs agree. Similarly, studies have shown that children are less likely to become car sick when elevated in a seat that provides a good outside view (Fischer, 1998).

Evidence of current problems has been well documented. Rickert (2000) found that 74% of the Marines being transported in an amphibious assault vehicle reported moderate to severe motion sickness symptoms after working at computer work stations. Cowings, Toscano, DeRoshia, and Tauson (1999) examined Soldier health and performance in a command and control vehicle (C2V) in an operational environment and found motion sickness was reported by 100% of the subjects with 55% indicating moderate to severe symptoms. The authors also report that 15% of the subjects experienced vomiting and that drowsiness was the most frequently reported symptom.

Airsickness can be more problematic than motion sickness occurring on the ground. An outside view doesn't necessarily help in aviation, because flight constantly presents sensory conflicts. During a coordinated turn, for example, the visual scene is that of a tilted horizon while the vestibular sense indicates a perfectly upright position. Uncoordinated maneuvers and turbulence provide even more complex conflicts. In a cloud, many vestibular sensations may be received while the visual system reports a featureless, horizonless void. Passengers are far more prone to motion sickness than are the pilots (DeHart & Davis, 2002). This is not surprising considering that motion sickness is often triggered by discrepancies between anticipated orientation and actual orientation. For pilots at the aircraft controls, knowledge of upcoming flight movements seems to offer some protection against acquiring the symptoms of airsickness as compared to passengers and crewmembers (DeHart & Davis).

Treatment of motion sickness

Nausea and vomiting (Stern, 2002) are the most common complaints of motion sickness and are mediated by central neurotransmitters. In response to visual and vestibular input, increased levels of dopamine stimulate the medulla oblongata's chemoreceptor trigger zone, which in turn stimulates the vomiting center within the reticular formation of the brain stem. The vomiting

center also is directly stimulated by motion and by high levels of acetylcholine. Therefore, most drugs that are used to prevent or ameliorate motion sickness symptoms target these neurotransmitters. While the precise action of these medications in preventing motion sickness is not known, most of these drugs fall into three classes: antidopaminergics, anticholinergics, and antihistamines (Drug Facts and Comparisons, 1999; Physician's Desk Reference, 2001). Alternative remedies such as acupuncture, acupressure, acustimulation, and hypnosis are becoming increasingly popular and many have been recommended for treatment of motion sickness (Blumenthal, Goldberg, & Brinkmann, 2000; Cummings & Ullman, 1997; Dobie & May, 1994; Ernst & Pittler, 2000; Brendley, Marti, & DiZio 2003; Yen, Fleur, Golding, & Gresty, 2003; Young, Chiang, Huang, Pan, & Chen, 2002).

The focus of this study is the assessment of one such alternative remedy: the use of stroboscopic environments as a countermeasure when retinal slip is a significant factor in eliciting the motion sickness. Studies have shown that retinal image velocity (retinal slip) is considered to contribute to space and terrestrial motion sickness (Bos & Bles, 2004; Han et al., 2005). Retinal slip results when our eyes fail to hold an image stationary on the retina. This problem has implications for Soldiers who are visually engaged (e.g., reading and/or navigating) while being transported in the back of a variety of military vehicles. The use of stroboscopic vision is a possible solution to the problem of motion sickness related to retinal slip. Stroboscopic illumination is believed to prevent retinal slip by "providing snapshots of the visual environment" that are brief enough so each image is stationary on the retina (*Stroboscopic*, 2005). It is believed that prevention of retinal slip will reduce symptoms of motion sickness. This field of research began serendipitously as a result of a research project exploring adaptation of the vestibulo-ocular reflex employing optically reversing prisms which induced motion sickness symptoms (Melvill-Jones & Mandl, 1981). Melvill-Jones and Mandl discovered what they term a "particularly interesting" finding: "none of the subjects ever experienced nausea or associated symptoms" in 4 hertz (Hz), or cycles per second, stroboscopic light (strobe-light conditions).

The results of a study by Reschke, Somers, and Ford (2006), comparing the efficacy of strobe lighting and shutter glasses (both at 4 Hz) as a treatment for motion sickness, were very similar to those of Melvill-Jones and Mandl. Reschke et al. reported that stroboscopic illumination, both by ambient illumination or by shutter glasses, reduced the severity of motion sickness symptoms and "appears to be an effective countermeasure where retinal slip is a significant factor in eliciting motion sickness due to either self- or surround-motion." A review of these studies provides compelling evidence that stroboscopic technology may provide a method of preventing motion sickness in the mounted Warfighter. Estrada (2007), in a preliminary, but suggestive, airborne test of 4 and 8 Hz stroboscopic shutter glasses in the U.S. Army Aeromedical Research Laboratory's (USAARL) research helicopter, found the results to be consistent with the encouraging reports by Reschke et al. and Han et al. (2005). Subjects' Motion Sickness Questionnaire (MSQ) data revealed the 8 Hz setting produced lower motion sickness ratings compared to the 4 Hz setting. Although efficacy of the shutter glasses as a countermeasure for motion sickness was not implied by this test, the results did indicate that stroboscopic technologies, such as the shutter glasses, demonstrated promise and should be explored as a non-pharmacological motion sickness prevention strategy.

Recently, Webb et al. (2009) tested the idea of applying stroboscopic illumination to the passenger area of moving military vehicles as a countermeasure for motion sickness. This study used a multi-axis ride simulator to reproduce the motion profiles of airborne and amphibious vehicles to examine the effectiveness of 4 and 8 Hz stroboscopic environments. Although there was evidence of the effectiveness of stroboscopic illumination in reducing motion sickness in the subjective reports of the subjects, especially for the 8 Hz condition, this study did not provide the conclusive evidence required to recommend this promising technology for operational applications. However, the study did demonstrate the need for further examination of a more motion-sickness susceptible population for future research examining stroboscopic illumination as a motion sickness countermeasure.

Flicker vertigo and photosensitive epilepsy

Despite the research reporting the benefits of stroboscopic vision as a countermeasure for motion sickness, there must be an awareness that a minute percentage of the population is said to be adversely affected by flickering or flashing light. To date, two very rare maladies known as flicker vertigo and photosensitive epilepsy have been reported.

Rash (2004) described flicker vertigo as an imbalance in brain cell activity caused by exposure to low-frequency flickering or flashing of a relatively bright light such as a rotating beacon, strobe light, or sunlight seen through a turning propeller or rotor. It is said to occur at flashing/flicker rates of 4 to 20 Hz (Headquarters, Department of the Army, 2000; Heinle, 2001) and to result in nausea, dizziness, a spinning sensation, headache, panic, confusion, and, in rare cases, seizures and loss of consciousness (Rash). In normal individuals, there is little evidence that it causes spatial disorientation or clinical vertigo (Bynum & Stern, 1969; DeHart & Davis, 2002). In fact, Wick (1982) insists there is no such thing as flicker vertigo, and that the original reference was merely speculation.

According to the National Society for Epilepsy (NSE) (n.d.) and the Epilepsy Foundation (n.d.), photosensitive epilepsy (sometimes called flicker-induced epilepsy) has been reported in about 3 to 5% of the people who have epilepsy (1 in 200) and is more common in children and adolescents between the ages of 5 and 19 years. Binnie and Jeavons (1992) write that photosensitivity is most often detected at the age of 12 to 14 years although the history often suggests that it may have been present for some years before it is recognized and that two-thirds of the patients are female. The NSE lists the most common triggers as visual fire alarm strobe lights, television screens, video games, computer monitors, and exposure to strong environmental lights. A study of the widely-reported *Pokemon Phenomenon,* in which many Japanese children and some adults developed various degrees of neurologic problems, including seizures, while watching the popular animated television show *Pokemon,* found that “individuals in whom definitive seizures were induced had some predisposition to seizures” (Furusho et al., 2002). The rarity of this condition is documented in a study by Doose and Waltz (1993) whereas only 2 to 10% of individuals possessing EEG markers of seizure liability (photoparoxysmal response) actually developed seizures due to photic stimulation. The frequency range at which seizures are induced varies according to the information source. According to the NSE and Epilepsy Foundation, seizures are generally triggered by flashes between 5 and 30 Hz while

DeHart and Davis (2002) suggest the triggering frequencies are between 8 to 14 Hz. As expected, the critical frequency varies from person to person although it is uncommon to have photosensitivity to flashes below 5 Hz (NSE).

Military relevance

Soldiers must be ready to execute missions at any time during or following transportation, so minimizing the symptoms of motion sickness is critical. Many of the currently available pharmaceutical countermeasures are given orally and often produce sedation, which is unacceptable in terms of mission effectiveness. Hence, the development of non-traditional, non-pharmacologic motion sickness and nausea remedies could be of great benefit to the operational military community.

Research objectives

The purpose of this study was to determine the effectiveness of an 8 Hz stroboscopic environment for alleviating airsickness symptoms and ameliorating performance decrements related to retinal slip. It was hypothesized that performance would be better after the stroboscopic condition compared to the non-stroboscopic condition. Specifically, subjects would report less motion sickness symptoms and perform better on the tests of weapons simulation and cognitive abilities after the stroboscopic condition than after the non-stroboscopic condition.

Methods

Research design

The independent variable of interest was *lighting condition,* and its two levels were stroboscopic lighting and non-stroboscopic lighting. The scores were baseline corrected, as subjects completed a baseline testing session in a laboratory setting. The study utilized a within-subjects design, requiring each subject to experience all testing conditions. The order of the lighting conditions was randomized to minimize order effects.

Subjects

Eligible subjects were male and female U.S. Army active duty Soldiers from the local area who were between the ages of 19 (the age of majority in Alabama) and 40 years. There were no gender restrictions, but females were screened for pregnancy before each flight to eliminate the possible confound of increased susceptibility of nausea and vomiting. There were no eligibility restrictions regarding current or former military occupational specialty (MOS). However, as individuals can adapt to motion sickness inducing symptoms, helicopter flight experience was limited to less than 10 hours. This exclusion criterion has been used in previous motion sickness

studies at USAARL (Estrada et al., 2006). A power analysis indicated that a total of 20 subjects were needed for the study.

An additional inclusion criterion was history of motion sickness susceptibility as measured by the Motion Sickness Susceptibility Questionnaire-Short (MSSQ-Short; Golding, 2006). The questionnaire evaluates a person's motion sickness experiences with nine types of motion (appendix A). Subjects rate how often they felt sick or nauseated on a 0 to 3 scale. Scores range from 0 to 54 and norms are provided. Higher scores indicate a greater susceptibility. Given the strength of the motion sickness stimuli, subjects reporting scores less than 11.3 (50^{th} percentile) were excluded.

Exclusion criteria included a history or currently active condition of epilepsy, photosensitive epilepsy, or seizure disorder (other than simple pediatric febrile seizure), as well as any musculoskeletal or neurologic disorders with deficits, profiles, or restrictions precluding the ability to load/unload aircraft or expeditiously egress in case of emergency. In addition, the use of a medication affecting vestibular function or with a propensity to promote or prevent and/or mask motion sickness symptoms (e.g., dizziness, nausea, emesis, drowsiness, pallor, diaphoresis) was disqualifying.

Equipment

USAARL's UH-60A Black Hawk helicopter was used for the test flights. The selected flight profile (appendix B) has proven nauseogenic in previous USAARL motion sickness protocols (Estrada et al., 2006) by varying the movement of the aircraft and eliminating the outside visuals for the passenger (by covering the windows with blackout curtains). The flight lasted approximately 30 minutes. A 3-dimensional representation of the flight profile is depicted in figure 1.

A 750-watt strobe light (Eliminator Lighting), allowing the selection of 1 to 20 flashes per second, was used to create the stroboscopic environment. The device was mounted in the cabin section of the aircraft. A curtain separated the cabin area from the cockpit, so the stroboscopic environment would not interfere with the pilots' flying duties. The strobe light received technical review and was added to the Air Worthiness Release (AWR) for the aircraft. For the non-stroboscopic condition, a reading light was provided by a 36-watt light bulb overhead. Figure 2 illustrates the positioning of the stroboscopic light source and curtain in the aircraft.

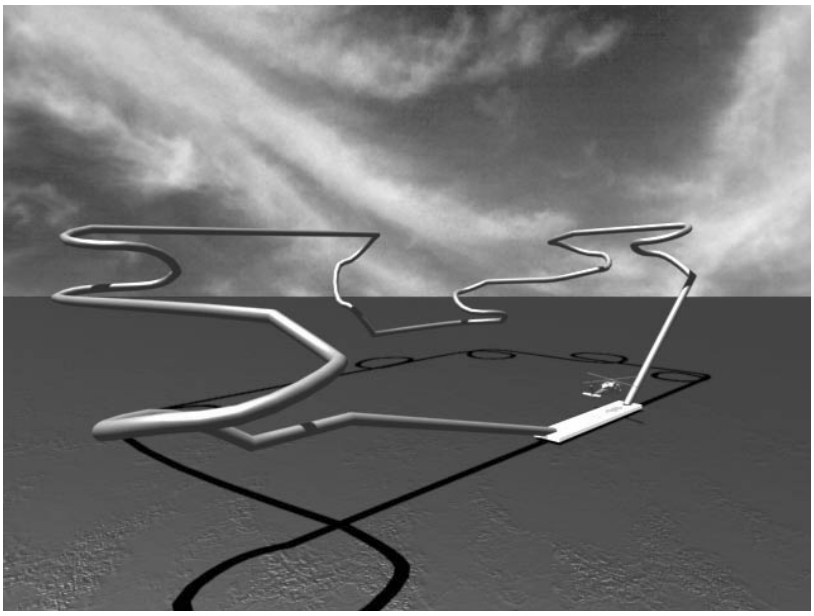


Figure 1. Flight profile.

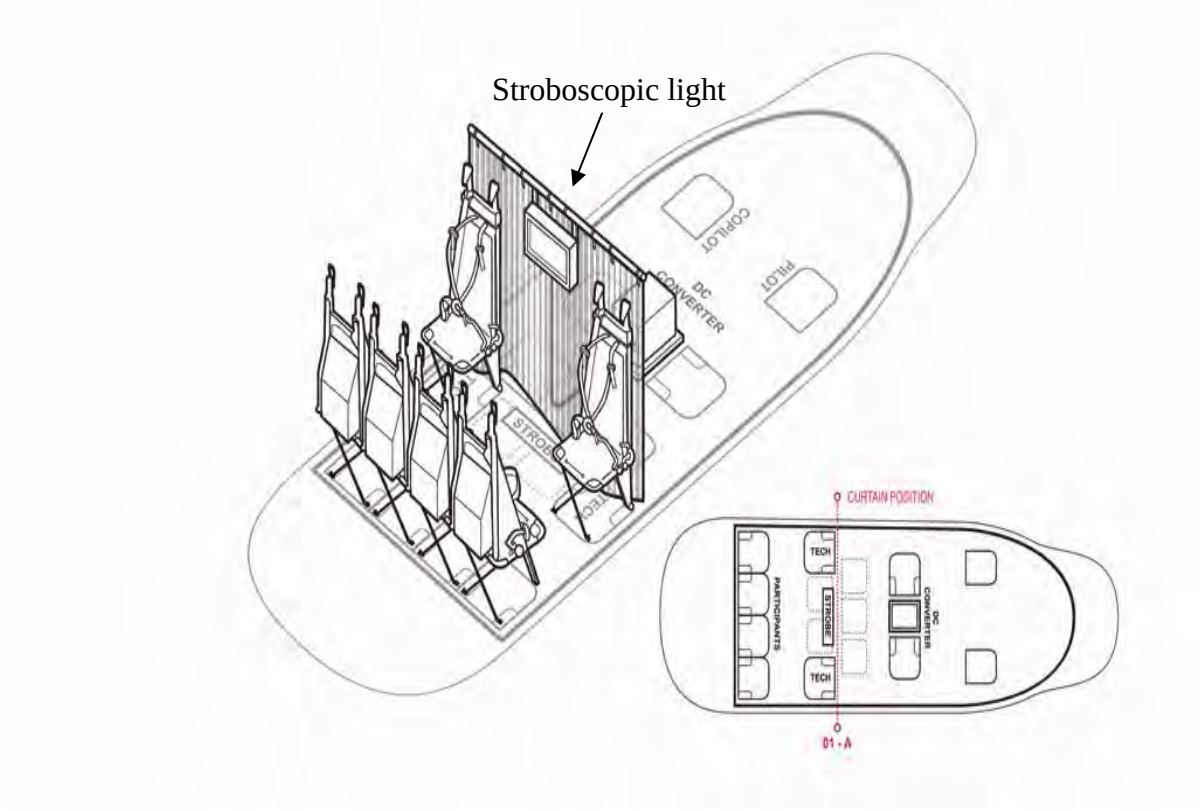


Figure 2. Schematic of strobe placement in aircraft.

Dependent measures

The five dependent measures included in the test battery were the Motion Sickness Questionnaire, the Psychomotor Vigilance Task, a weapons marksmanship task utilizing the Engagement Skills Trainer 2000, a time estimation task, and the Rapid Visual Information Processing test. Detailed information about each measure is provided below.

Motion Sickness Questionnaire

The Motion Sickness Questionnaire (MSQ) was used to measure research subjects' subjective symptoms of motion sickness (Kellogg, Kennedy, & Graybiel, 1965). The MSQ is a validated, self-report form consisting of 28 items that are rated by the subject in terms of severity on a 4-point scale (appendix C). The MSQ yields four scores, namely a nausea, oculomotor, disorientation and total score. Higher values for all four scores are indicative of greater symptoms experienced. Nausea scores are derived from the self-assessments of general discomfort, increased salivation, sweating, nausea, difficulty concentrating, stomach awareness, and confusion. Oculomotor disturbance scores are derived from self-assessments of general discomfort, fatigue, headache, eye strain, difficulty focusing and concentrating, and blurred vision. Disorientation scores combine reports of difficulty focusing, nausea, fullness of the head, blurred vision, dizziness with eyes open and/or closed, and vertigo. The total symptom severity score is the aggregate of all of the symptoms.

Psychomotor Vigilance Task

Changes in basic reaction time were assessed using the Psychomotor Vigilance Task (PVT). A previous motion sickness study by Estrada et al. (2006) observed the sensitivity of this test to the drowsiness and general malaise often associated with motion sickness. The 10-minute version of the PVT was administered on a hand-held personal digital assistant (PDA). This device was validated at Walter Reed Army Institute of Research (figure 3; Thorne, Johnson, Redmond, Sing, & Belenky, 2005). It has been reported that there are no learning effects with the PVT beyond the first administration (Van Dongen, Belenky, & Krueger, 2010). Subjects are required to monitor a liquid crystal display (LCD) on which a stimulus is presented randomly every 1 to 10 seconds. The subject responds by pressing a button each time a target appears. Data collected from the PVT includes mean response time, number of responses over 500 milliseconds (i.e., lapses), and the slope of the reciprocal response times (RRT slope) during the 10-minute test, a measure of time-on-task effect (Lim & Dinges, 2008). Higher values for the reaction time and lapse data indicate poor performance, where as the more negative the slope, the greater the performance decline over the 10-minute task.

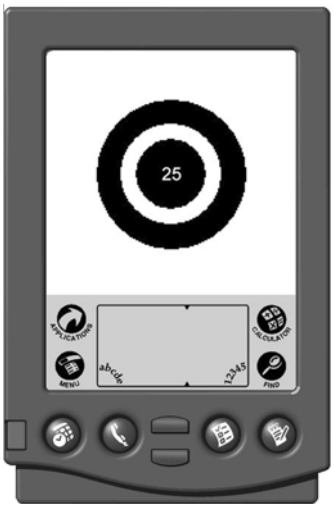


Figure 3. Hand-held PVT device (Thorne et al., 2005).

Engagement Skills Trainer 2000

It is common for Soldiers being transported in the back of helicopters to be transported to a conflict area and be expected to fire a weapon upon disembarking. Therefore, a marksmanship task was included in the present study as a particularly relevant assessment of stroboscopic environments as a motion sickness countermeasure.

The Engagement Skills Trainer (EST) 2000 is a U. S. Army's small arms training device. A subject shoots from a lane (the USAARL laboratory has a five-lane configuration) at "targets" which appear on a projection screen at a distance of 26 feet 3 inches from the firing line (figure 4). The weapons have been modified for use with the EST 2000 but maintain their form, fit, feel, and function. During this study, subjects performed a standard 40-target marksmanship task using a rifle. The scenario lasts approximately 4 minutes and consists of 40 timed targets at ranges from 50 to 300 meters (m) with 40 rounds of ammunition. The scenario entails the subject shooting from three positions: prone supported, prone unsupported, and kneeling. Dependent variables of interest include proportion of hits, mean reaction time to fire, mean shot radius (accuracy in the form of distance of the shot from center of mass of target), and root mean square (RMS) distance from target center of mass as a measure of aiming drift (figure 5). During the practice session, subjects zero their weapon, or align a laser sensor which is the equivalent of the mechanical weapon zero.

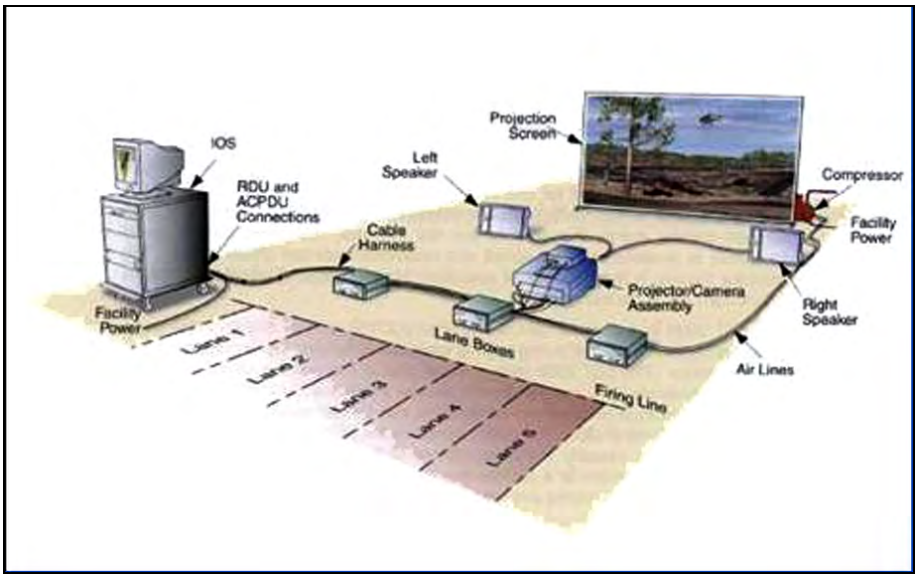


Figure 4. EST 2000 set-up (Anthony, 2006).

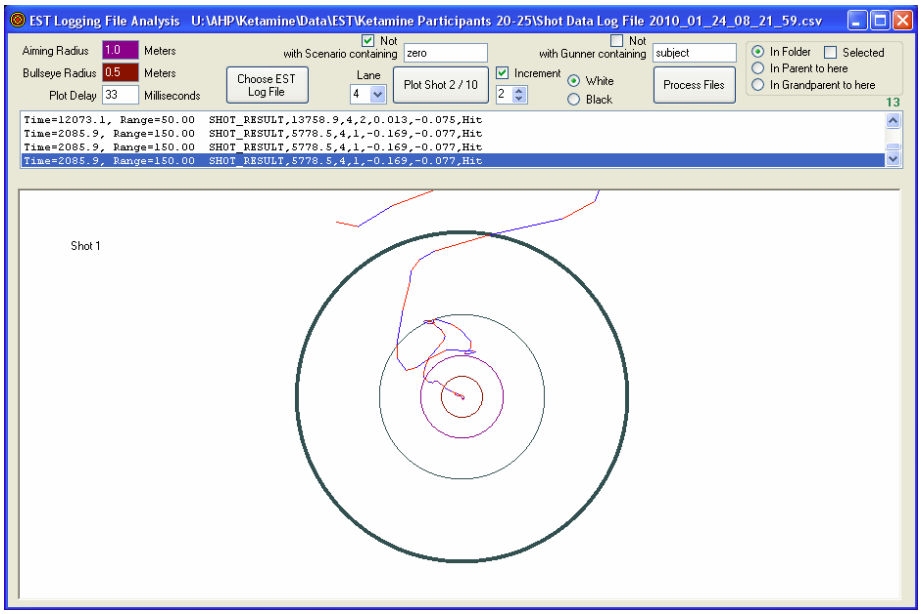


Figure 5. Screen capture of aiming trace to determine root mean square.

Time estimation task

Motion sickness has been shown to negatively affect time estimation abilities (Graybiel et al., 1965). Therefore, the present study included a test of time estimation to examine the effectiveness of stroboscopic illumination as a motion sickness countermeasure. In the task, the subject observes a small square traveling at constant speed from the top of the computer screen toward the bottom of the screen. However, a wall obstructs the bottom of the screen, preventing the subject from watching the square reach the bottom of the screen. The individual is required to press a computer key when he/she estimates that the object will reach the bottom of the screen. The time wall test from the Psychology Experiment Building Language (PEBL) Psychological Test Battery was used in the present study. A screen shot is provided in figure 6. The dependent variable of interest was the subjects' accuracy score: the absolute value of the difference between correct time and response time is divided by the correct time, so that a value close to 0 indicates better accuracy.

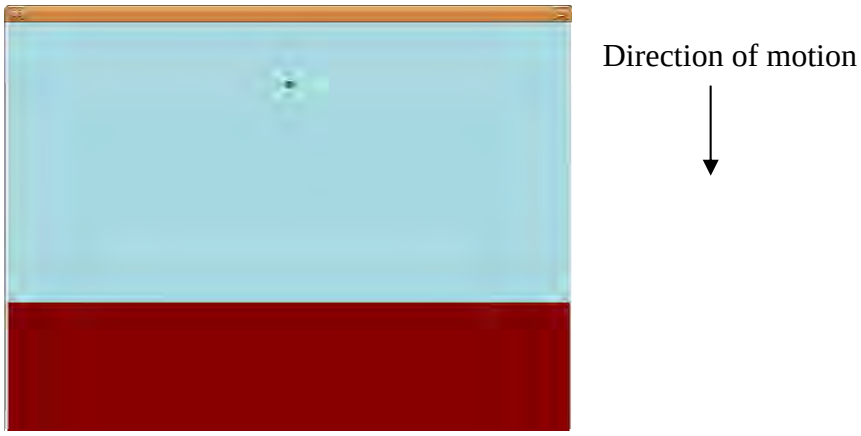


Figure 6. Screen capture of time wall task.

Rapid Visual Information Processing

Motion sickness has been shown to negatively affect cognitive performance. Specifically, complex tasks as well as tests of sustained performance are most negatively affected (Lawson, Kass, Kennedy, Muth, & Smith, 2003). The Rapid Visual Information Processing (RVP) test from the Cambridge Neuropsychological Test Automated Battery (CANTAB) was administered in the present study. It is a subtest of visual sustained attention with a small working memory component. A white box is displayed in the center of the computer screen, inside which digits from 2 to 9 are displayed in a pseudo-random order, at the rate of 100 digits per minute. The subject must detect consecutive odd or even sequences of digits (for example, 3-5-7) and respond by pressing the touch pad (figure 7). The dependent variable of interest was A' (a prime), a measure of performance in detecting sequences.

Figure 7. Screen capture of the RVP task.

Procedure

The study protocol was approved by the Headquarters, U.S. Army Medical Research and Materiel Command Institutional Review Board (HQ USAMRMC IRB). Written informed consent was obtained from all volunteers. Subjects were randomly assigned to one of five groups to allow for five groups of four people to complete the test sessions. This grouping was limited by the number of available seats (forward facing) in the aircraft.

During the practice session, subjects were given an opportunity to practice the dependent measures used in the assessment battery one time as well as zero their weapons on the EST 2000. After completing the practice session, subjects were allowed a 10-minute break and then completed the tests an additional time for their baseline scores.

The next day, subjects completed their first of two flights. The order of the lighting conditions was randomly assigned to minimize order effects. However, due to the odd number of flights (five flights of four subjects), three of the five groups experienced the stroboscopic condition first. In other words, 12 of the 20 subjects experienced the stroboscopic condition first. Subjects sat in the back row of forward facing seats in the aircraft. For both flights, subjects were assigned the same seating position in order to avoid the introduction of a potentially confounding variable of seating position. To induce retinal slip, subjects performed a reading comprehension task during each flight. Subjects' answers to the reading comprehension questions were scored to verify they were reading (and causing retinal slip). Subjects' heads were not restrained. Flight 1 and 2 were scheduled one week apart. The time of day regarding the flights was controlled for each group, with flights 1 and 2 occurring at approximately the same time.

A member of the research staff was onboard all flights. The flight profile was divided into two, 15-minute segments. If a subject felt too sick to continue, the crew was prepared to land momentarily, allowing the subject to disembark and be received by a member of the research staff. None of the subjects requested to end participation early.

After completion of the test flight and landing at USAARL, subjects completed the MSQ while still in the helicopter. This allowed for immediate measurement of motion sickness symptoms experienced by the subjects. Subjects exited the helicopter and were escorted to the testing facilities at USAARL (an approximately 3-minute walk). They then completed the remainder of the assessment battery according to the order presented in appendix D.

After completing the flight and assessment battery, subjects met with a study physician to complete a brief exit medical screening to ensure there were no lingering effects of the motion environment and they were fit to be released from the study.

Results

All statistical analyses were conducted using SPSS® 13.0 with significance set at an alpha level of .05. As previously mentioned, subjects' reading comprehension task were scored to verify that they were performing the reading task. Upon examination, two subjects did not attempt any questions; therefore, they were eliminated from the analysis. Results are for 18 subjects, unless stated otherwise.

Demographic data

Eighteen subjects were included in the data analysis. One subject was female. The average age of the subjects was 26.0 years (± 4.12). Subjects' average MSSQ-Short score was 22.53 (± 6.56).

MSQ data

Subjects completed the MSQ at the baseline session and immediately after completing each of the test flights. Recall the four dependent measures from the MSQ are the nausea, oculomotor, disorientation, and total scores.

A test comparing scores from flight 1 to flight 2 indicated there was an order effect for the oculomotor scores approaching significance, with subjects reporting higher oculomotor scores after flight 1 (M = 37.1) than flight 2 (M = 26.9; p = .053 (two-tailed)). This is most likely due to the number of subjects who received the stroboscopic flight first (11/18). An attempt was made to randomize the order of the lighting conditions, but the constraints of the flight schedule (five flights of four subjects) did not allow for an equal number of subjects to experience each lighting condition first. There were no significant order effects for the remaining three scores of the MSQ.

Figure 8 presents the four MSQ scores by lighting condition. Difference scores were calculated by subtracting the baseline score from each of the post-flight scores, with higher scores indicating a greater increase in symptoms from baseline. The data were analyzed using a paired-samples t-test by the two lighting conditions (stroboscopic or non-stroboscopic) and the results are presented in table 1. Nausea scores were significantly greater after the non-stroboscopic flight compared to the stroboscopic flight. Also, oculomotor scores were greater after the stroboscopic flight, but the difference only approached significance.

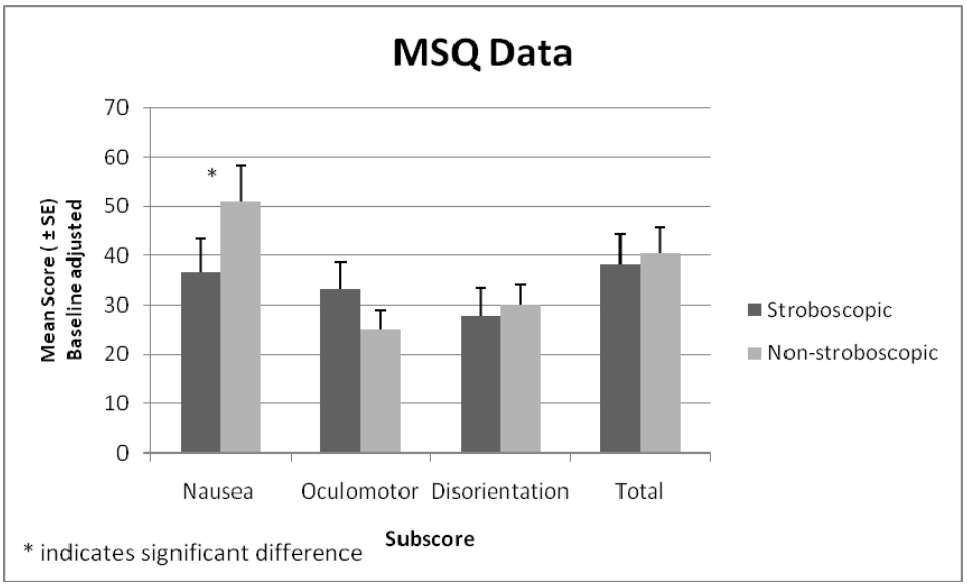


Figure 8. Mean ± SE MSQ scores by lighting condition.

Table 1.
Results of paired samples *t*-test for MSQ data.

MSQ Subscore	*t* value	*p* value (one-tailed)
Nausea	-1.942	.034*
Oculomotor	1.668	.057
Disorientation	-.388	.351
Total	-.340	.369

* indicates significance at $\alpha = .05$

The most commonly reported MSQ symptoms reported after the stroboscopic condition were eye strain, general discomfort, sweating, difficulty focusing, and nausea. The most frequently reported symptoms after the non-stroboscopic condition were sweating, general discomfort, stomach awareness, nausea, and difficulty focusing. A frequency count for all MSQ symptoms is included in appendix E.

PVT data

Subjects completed the PVT on baseline and after completing each of the test flights. Dependent variables of interest included mean reaction time, mean number of lapses, and the mean slope of the RRT. There were no order effects, as data from after flight 1 were not significantly different from data from flight 2 for the reaction time data (p =.183), lapses (p = .122), or slope data (p = .392).

Figures 9 through 11 present the mean reaction time, number of lapses, and mean slope data by lighting condition. Difference scores were calculated by subtracting the baseline score from each of the post-flight scores. Higher scores with regard to the reaction time and lapse data are indicative of poorer performance compared to baseline, whereas the more negative the slope, the faster the decline of response speed across the ten minutes of testing. The data were analyzed using a paired-samples *t*-test by the two lighting conditions (stroboscopic or non-stroboscopic) and the results are presented in table 2. There were no significant differences between the lighting conditions for either the reaction time or lapse data. However, the mean RRT slope was significantly more negative after the non-stroboscopic condition compared to the stroboscopic condition, indicating a greater performance decline over the 10 minute task.

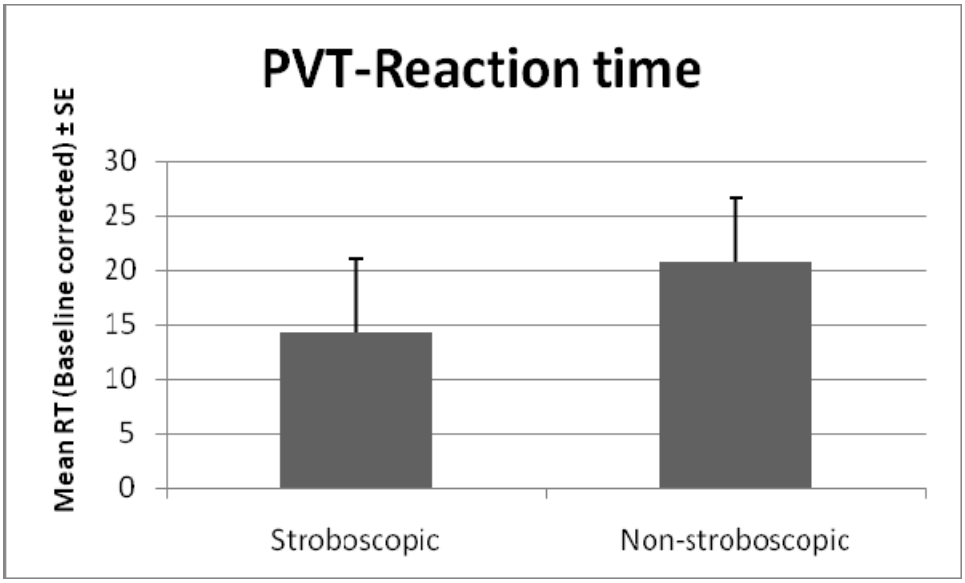


Figure 9. Mean ± SE PVT reaction time data by lighting condition.

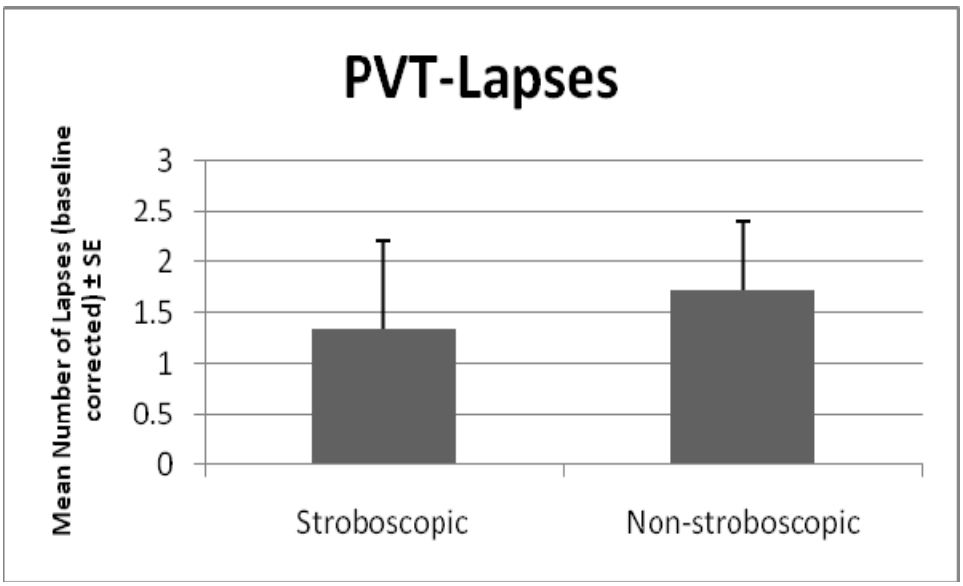


Figure 10. Mean ± SE PVT lapse data by lighting condition.

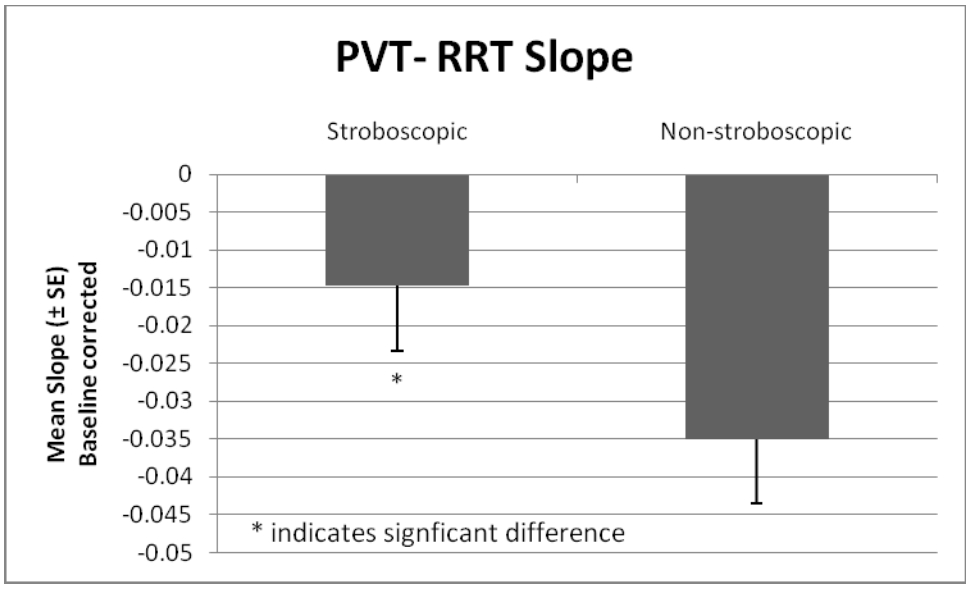


Figure 11. Mean ± SE PVT RRT slope data by lighting condition.

Table 2.
Results of paired samples *t*-test for PVT data.

Measure	*t* value	*p* value (one-tailed)
Mean RT	-.787	.221
Lapses	-.304	.383
RRT slope	2.567	.010*

* indicates significance at α =.05

EST data

Subjects completed the standard 40-target record fire on baseline and after completing each of the test flights. Dependent measures include reaction time, accuracy, shot radius, and RMS. Data from each shooting position (prone supported, prone unsupported, kneeling) were analyzed separately.

Prone supported

There were no order effects, as data from after flight 1 were not significantly different from data from flight 2 for the reaction time, accuracy, radius, and RMS data ($p > .05$).

The data were analyzed using a 6 (target distance: 50 m, 100 m, 150 m, 200 m, 250 m, 300 m) x 2 (lighting condition: stroboscopic, non-stroboscopic) repeated measures ANOVA. For all four dependent measures, data from one subject was missing, and the resulting data analysis included 17 data sets. As shown in table 3, there were no significant main effects of lighting condition or significant interactions for any of the dependent measures. In cases where the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied. Figure 12 presents mean reaction time, accuracy, shot radius, and RMS data by lighting condition and distance.

Table 3.
Results of repeated measures ANOVA for prone supported rifle marksmanship.

Position	Effect	Dependent variable	df	F	*p*	partial η^2
Prone supported	Lighting condition	reaction time	1	3.186	.093	.166
		accuracy	1	.374	.549	.023
		shot radius	1	.551	.469	.033
		RMS	1	.697	.416	.042
	Target distance	reaction time	2.671	3.624	.024	.185
		accuracy	5	.257	.935	.016
		shot radius	1.004	8.859	.009	.356
		RMS	1.021	6.605	.020	.292
	Interaction	reaction time	5	.769	.575	.046
		accuracy	5	.995	.426	.059
		shot radius	1.001	.461	.507	.028
		RMS	1.005	.519	.482	.031

The main effect of target distance was significant for the reaction time, shot radius, and RMS data. Subsequent post hoc pairwise comparisons were conducted and the results are presented in appendix F. To reduce the risk of a Type I error, a Bonferroni correction was applied ($\alpha = .05/15 = .003$). Given the stringent alpha level, differences between the target distances failed to reach significance.

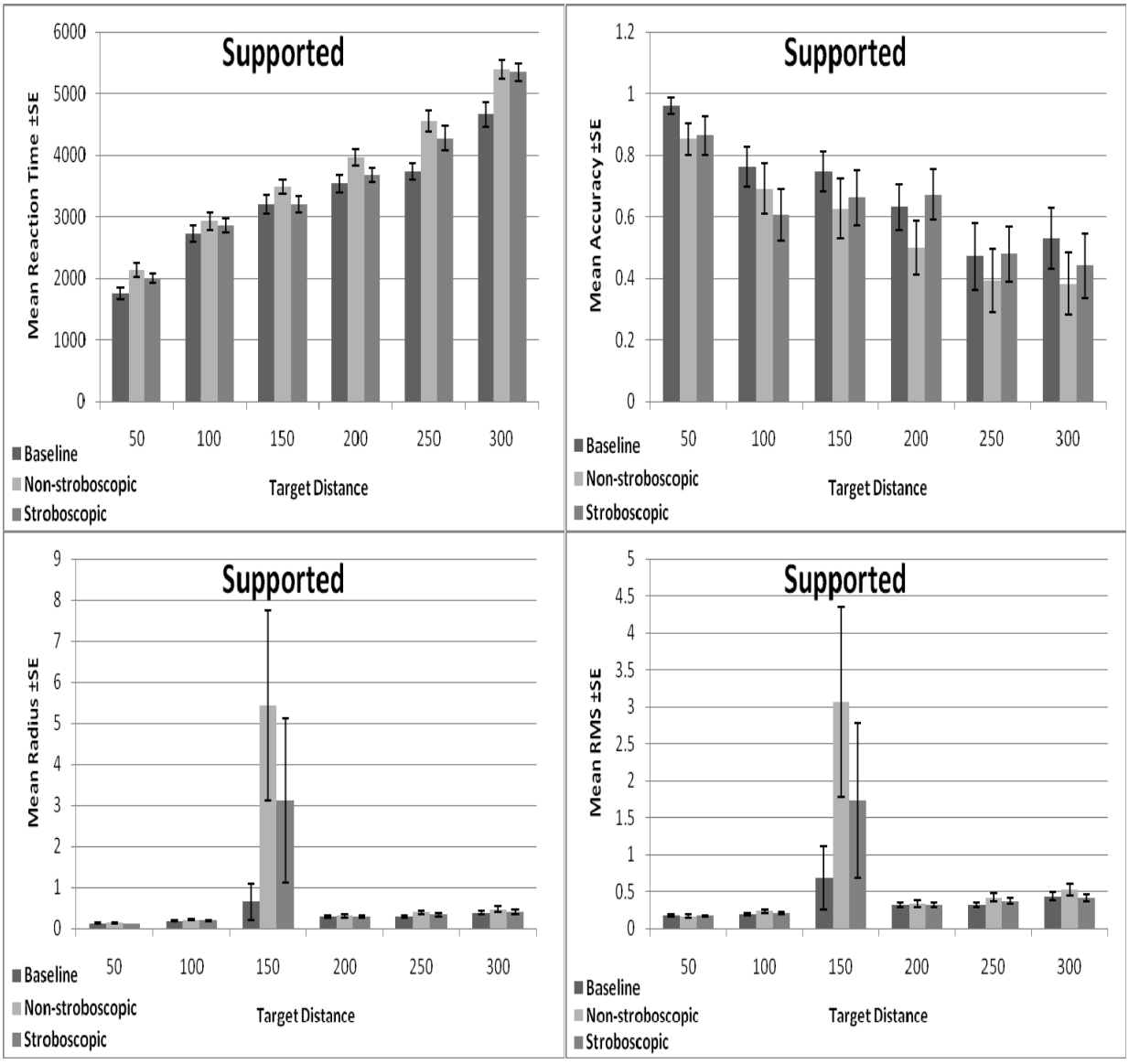


Figure 12. Mean ± SE EST prone supported data by lighting condition and target distance.

Prone unsupported

There were no order effects for the accuracy, radius, and RMS data (p >.05), as data from after flight 1 were not significantly different from data from flight 2. However, there was a significant order effect for the reaction time data (p = .015), with subjects' reaction times significantly slower after flight 2 compared to flight 1. Remember, 11 of the 18 subjects received the stroboscopic condition first.

The reaction time, accuracy, and shot radius data were analyzed using a 4 (target distance: 150 m, 200 m, 250 m, 300 m) x 2 (lighting condition: stroboscopic, non-stroboscopic) repeated

measures ANOVA. Due to missing data, these analyses included data from 10 subjects. Due to equipment errors, RMS data was only collected for the 150 m, 200 m, and 250 m targets. Therefore, the RMS data were analyzed using a 2 x 3 repeated measures ANOVA. As shown in table 4, there were no significant main effects of lighting condition for any of the dependent measures. In addition, there were no significant main effects of target distance or interactions. In cases where the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied. Figure 13 presents mean reaction time, accuracy, shot radius, and RMS data by lighting condition and distance.

Table 4.
Results of repeated measures ANOVA for prone unsupported rifle marksmanship.

Position	Effect	Dependent variable	df	F	*p*	partial η^2
Prone unsupported	Lighting condition	reaction time	1	.005	.945	.001
		accuracy	1	.000	.997	.000
		shot radius	1	.015	.906	.002
		RMS	1	.030	.865	.002
	Target distance	reaction time	3	.245	.864	.027
		accuracy	3	.484	.696	.051
		shot radius	1.004	3.467	.095	.278
		RMS	1.003	1.645	.217	.088
	Interaction	reaction time	3	1.724	.186	.161
		accuracy	3	2.126	.120	.191
		shot radius	1.001	.038	.849	.004
		RMS	1.003	.055	.819	.003

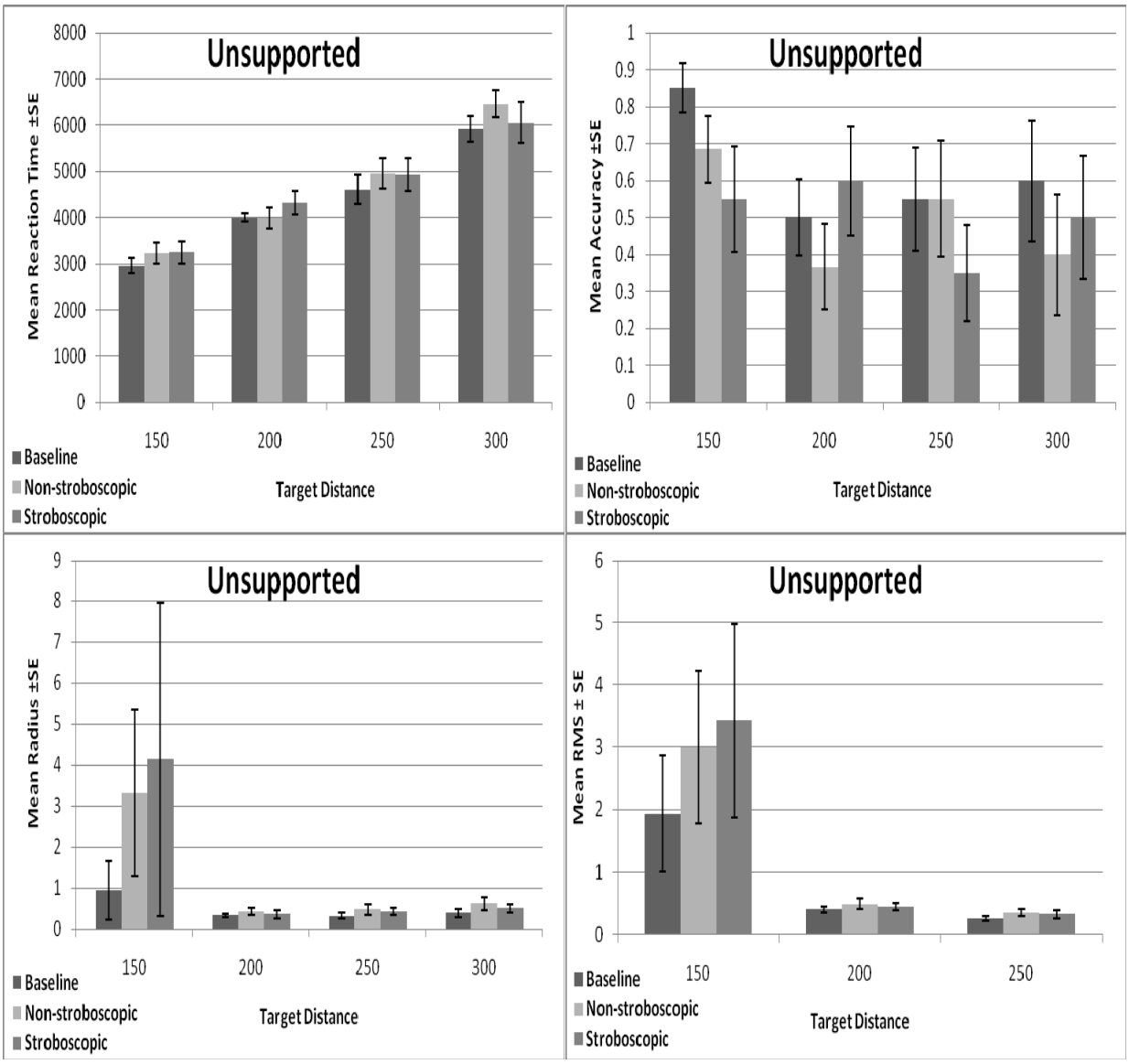


Figure 13. Mean ± SE EST prone unsupported data by lighting condition and target distance.

Kneeling

There were no order effects, as data from after flight 1 were not significantly different from data from flight 2 for the reaction time, accuracy, radius, and RMS variables (p >.05).

The data were analyzed using a 3 (target distance: 50 m, 100 m, 150 m) x 2 (lighting condition: stroboscopic, non-stroboscopic) repeated measures ANOVA. As shown in table 5, there were no main effects of lighting condition for any of the dependent measures. In cases where the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied. Figure 14 present mean reaction time, accuracy, shot radius, and RMS data by lighting condition and distance.

The main effect of target distance was significant for the RMS data. Subsequent post hoc pairwise comparisons were conducted and the results are presented in appendix F. To reduce the risk of a Type I error, a Bonferroni correction was applied ($\alpha = .05/3 = .017$). Given the stringent alpha level, differences between the target distances failed to reach significance.

Table 5.
Results of repeated measures ANOVA for kneeling rifle marksmanship.

Position	Effect	Dependent variable	df	F	*p*	partial η^2
Kneeling	Lighting condition	reaction time	1	1.744	.204	.093
		accuracy	1	.007	.935	<.001
		shot radius	1	.118	.736	.007
		RMS	1	.052	.822	.003
	Target distance	reaction time	1.506	.377	.631	.022
		accuracy	2	1.045	.363	.058
		shot radius	1.000	1.373	.257	.075
		RMS	1.002	4.782	.043	.220
	Interaction	reaction time	2	3.078	.059	.153
		accuracy	2	3.00	.063	.150
		shot radius	1.000	.116	.737	.007
		RMS	1.001	.070	.795	.004

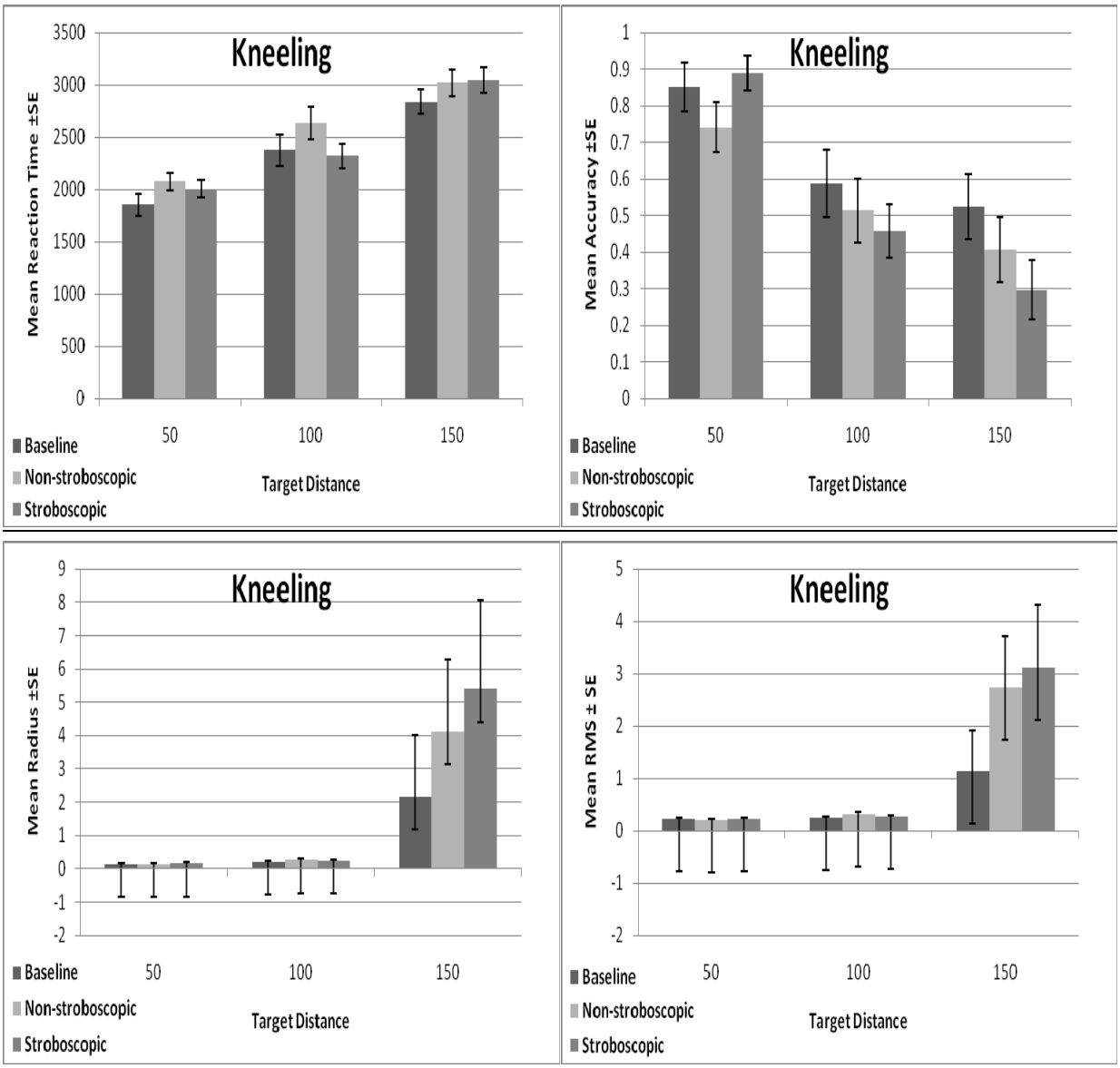


Figure 14. Mean ± SE EST kneeling data by lighting condition and target distance.

Time estimation data

Subjects completed the time estimation task on baseline and after completing each of the test flights. The dependent variable of interest was the subjects' accuracy score, where a value close to zero indicates better accuracy. There were no order effects, as data from after flight 1 were not significantly different from data from flight 2 (p = .667).

Figure 15 presents the mean accuracy data by lighting condition. Difference scores were calculated by subtracting the baseline score from each of the post-flight scores. The data were analyzed using a paired-samples t-test by the two lighting conditions (stroboscopic or non-

stroboscopic). Subjects' accuracy after the stroboscopic flight did not differ significantly from their accuracy after the non-stroboscopic flight ($t(17) = .513$, $p = .307$, one-tailed).

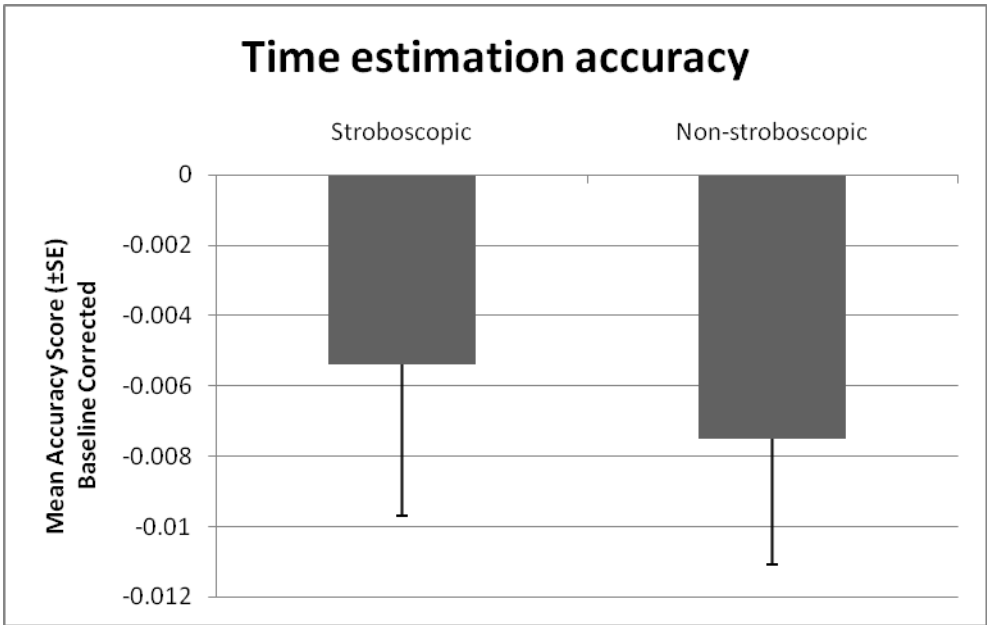


Figure 15. Mean ± SE Time estimation accuracy data by lighting condition.

RVP data

Subjects completed the RVP task on baseline and after completing each of the test flights. The dependent variable of interest was A' (a prime), a measure of performance in detecting sequences. Higher scores are indicative of better performance. There were no order effects, as data from after flight 1 were not significantly different from data from flight 2 ($p = .991$).

Figure 16 presents the mean A' score by lighting condition. Difference scores were calculated by subtracting the baseline score from each of the post-flight scores. The data were analyzed using a paired-samples *t*-test by the two lighting conditions (stroboscopic or non-stroboscopic). Subjects' scores after the stroboscopic flight were significantly better compared to their scores after the non-stroboscopic flight ($t(17) = -1.886$, $p = .038$, one-tailed).

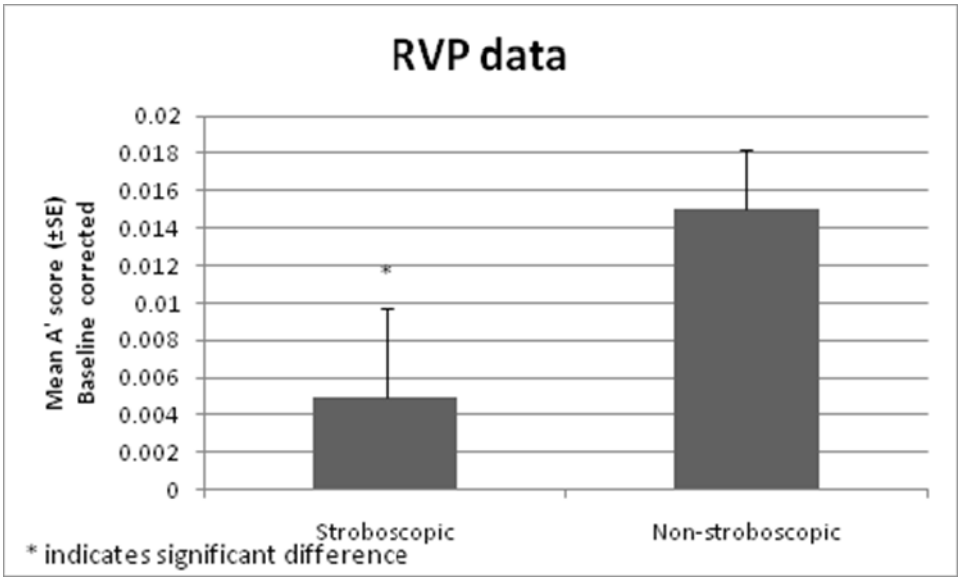


Figure 16. Mean ± SE RVP A' data by lighting condition.

Discussion

The present study built upon the results of Webb et al. (2009) by utilizing motion sickness-susceptible subjects, providing a more nauseating motion stimulus, and using only the 8 Hz stroboscopic setting. The stroboscopic condition reduced subjective reports of nausea and resulted in better performance on tests of sustained attention than the non-stroboscopic condition.

The MSQ was administered immediately upon landing after the test flights, when motion sickness symptoms would most likely be at peak presentation. In both lighting conditions, nausea scores were the highest of the three MSQ subscores. Although the stroboscopic condition reduced nausea scores, it increased oculomotor scores. The oculomotor subscale includes such symptoms as eyestrain, headache, and blurred vision. Similar results were found in previous studies, with the stroboscopic condition increasing symptoms of eyestrain (Webb et al., 2009; Estrada, 2007). However, not everyone reported eyestrain symptoms under the stroboscopic condition, and more information is needed to perhaps predict who may develop oculomotor symptoms under stroboscopic conditions. If there are individual differences with regard to developing these symptoms, perhaps individual stroboscopic shutter glasses would be more appropriate than overhead cabin lighting as a motion sickness countermeasure.

The drowsiness and mood changes associated with motion sickness have been referred to as the *sopite syndrome* (Graybiel & Knepton, 1976). Other symptoms include a disinclination for work (physical and/or mental) and a lack of involvement in group activities. These symptoms are generally "interwoven" with other motion sickness symptoms but can sometimes be the sole manifestation of motion sickness. Johnson (2005) argues motion sickness affects one's proclivity to perform a task, not ability.

The PVT is a reaction time task that is sensitive to fatigue variables including time awake and time-on-task effects (Van Dongen, Belenky, & Krueger, 2010). They define the time-on-task effect as a progressive decline in performance the longer a person is required to sustain attention to perform a task. While there was not a significant main effect of lighting condition for the reaction time or lapse data, there was for RRT slope (the measure of time-on-task). The mean RRT slope was significantly more negative after the non-stroboscopic condition. The more negative the slope, the faster the decline of response speed. Castell, Gough, Cardenas, and Miller (2005) suggest this is indicative of a more rapid loss of the ability to sustain attention. The RVP subtest is also a measure of sustained attention. Subjects' performance on the A' measure was significantly better after the stroboscopic condition compared to the non-stroboscopic condition. An inability to sustain attention can have dangerous consequences, especially in operational environments.

As not all tests are sensitive to sleep deprivation, not all tests may be sensitive to the fatigue associated with motion sickness. Simple, monotonous tasks that lack environmental stimulation have been favored as tests most sensitive to sleepiness and sleep deprivation (Harrison & Horne, 2000). In the present study, it could be argued that the marksmanship and time estimation tasks were the less monotonous of the battery, given the short duration of the time wall (approximately 3 minutes to complete) and the anecdotal reports of the subjects' enjoyment of the marksmanship task.

One concern common to all motion sickness studies is the rapid resolution of symptoms. Upon removal from the nauseogenic environment, motion sickness symptoms tend to resolve quickly. Golding and Stott (1997) reported most individuals reported subjective recovery by 15 to 30 minutes. However, there are great individual differences with regard to how long motion sickness symptoms will last. There have been reports of symptoms lasting several hours (Harm, 2002). In the present study, there were approximately 30 minutes of testing after experiencing the nauseating flight, which began after an approximately 3-minute walk from the landing pad to the testing facilities. The rapid resolution of symptoms may have contributed to the lack of significance in the time estimation and marksmanship data. However, this is unlikely, given the order of the testing battery was randomized.

Limitations

One limitation of the present study was the seasonal weather differences that occurred during the data collection period, which began in September and finished in December. Weather data were collected, including heat index which combines air temperature and relative humidity. During the study period, the heat index ranged from 95°F to 37°F. One *a posteriori* hypothesis is that increased temperatures would contribute to greater symptoms of motion sickness, as measured by the MSQ. A correlational analysis was conducted, and the only significant correlation was found between oculomotor MSQ scores and the heat index of the strobe flight (r = -.495). However, the correlation was negative, indicating as heat index increased, oculomotor scores decreased. While there was not a significant difference between the mean heat index for the stroboscopic and non-stroboscopic lighting conditions (M = 80.94, 82.11, respectively), the inability to control for weather conditions is a limitation of applied field research.

Another limitation of the present study is the low power associated with the marksmanship data. As previously mentioned, there were incomplete data due to technical malfunctions, resulting in decreased sample size. The inability to find a significant difference between lighting conditions in the present study may be the result of insufficient power, or it may be that motion sickness does not have a measurable effect on marksmanship abilities. Dahlman, Nählinder, and Falkmer (2005) examined the effect of motion sickness on rifle targeting performance and found decreased shooting precision (in the kneeling position using 200 m targets) after being transported in a military vehicle. However, shooting performance was degraded only after the 45-minute transportation session and not after the 30-minute transportation session. Other studies have examined the effects of motion sickness on shooting performance and have found conflicting results (Lawson, McGee, Castaneda, Golding, Kass, & McGrath, 2009).

A final limitation of the present study was the fact that the subjects were not blinded to what lighting condition they were experiencing. This may have affected their subjective impressions regarding the effectiveness of stroboscopic countermeasures, resulting in a placebo effect. However, given the nature of the research, it was not possible to blind subjects to the lighting condition.

Conclusions

Results from the present study support the use of stroboscopic illumination as a non-pharmacological countermeasure for motion sicknesses related to retinal slip. However, there still are research questions regarding this technology. For example, there are questions regarding individual differences in developing eyestrain side effects after exposure to stroboscopic lighting. Also, Reschke et al. (2007) highlighted the need for additional research investigating the adaptability of individuals in stroboscopic conditions. Finally, this technology should be investigated in other forms of actual transportation (e.g., ground vehicles).

References

Anthony, D. 2006. EST 2000: Engagement Skills Trainer. Orlando, FL: Cubic Defense Application.

Binnie, C. D., & Jeavons, P. M. 1992. Photosensitive epilepsies. In J. Roger, M. Bureau, C. Dravet, F. E. Dreifus, A. Perret, and P. Wolf (Eds.), Epileptic syndrome in infancy, childhood and adolescence. London: John Libby.

Blumenthal, M., Goldberg, A., & Brinkmann, J. 2000. Herbal Medicine: Expanded Commission E Monographs. Newton, MA: Integrative Medicine Communications.

Bos, J. E., & Bles, W. 2004. Motion sickness induced by optokinetic drums. Aviation, Space, and Environmental Medicine. 75(2): 172-174.

Brendley, K. W., Marti, J., & DiZio, P. 2003. Motion Coupled Visual Environment (MOCOVE): Drug-Free Alleviations of Motion Sickness. U.S. Navy Air Command. Training Systems Division Report AR-08-03.

Bynum, J.A., & Stern, J.A. 1969. Painted helicopter main rotor blades and flicker-induced vertigo. Aerospace Medicine. 40(6): 622-626.

Castell, L. M., Gough, E., Cardenas, R., & Miller, J. C. 2005. Sleep deprivation in humans, immunodepression and glutamine supplementation. University of Oxford. Report No. SPC 03-3059.

Cowings, P. S., Toscano, W. B., DeRoshia, C., & Tauson, R. A. 1999. Effects of the Command and Control Vehicle (C2V) operational environment on Soldier health and performance. Moffett Field, CA: Ames Research Center. NASA Technical Memorandum 1999-208786.

Cummings, S., & Ullman, D. 1997. Everybody's Guide to Homeopathic Medicines. 3rd ed. New York, NY: Penguin Putnam.

Dahlman, J., Nählinder, S., & Falkmer, T. 2005. Perceived motion sickness and targeting performance. Linköping, Sweden: Swedish Defense Research Agency. Report number FOI-R-1735--SE.

DeHart, R. L., & Davis, J. R. 2002. Fundamentals of Aerospace Medicine, 3rd ed. Baltimore, MD: Williams and Wilkins.

Dobie, T. G., & May J. G. 1994. Cognitive-behavioral management of motion sickness. Aviation, Space, and Environmental Medicine. 65(10 Pt 2): C1-C20.

Doose, H., & Waltz, S. 1993. Photosensitivity – Genetics and clinical significance. Neuropediatrics. 24: 249-255.

Drug Facts and Comparisons. 1999. Facts and Comparisons. St. Louis, MO: 258-259.

Epilepsy Foundation. n.d. Photosensitivity and seizures. Retrieved 4 May 07 from http://www.epilepsyfoundation.org/about/types/triggers/photosensitivity.cfm.

Ernst, E., & Pittler, M. H. 2000. Efficacy of ginger for nausea and vomiting: a systematic review of randomized clinical trials. British Journal of Anaesthesia. 84(3): 367-371.

Estrada, A. 2007. Preliminary assessment of stroboscopic shutter glasses on motion sickness in helicopter passengers. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 2007-11.

Estrada, A., Leduc, P. A., Curry, I. P., Persson, J. L., Phelps, S. E., et al. 2006. Airsickness prevention in helicopter passengers: A comparison of four countermeasures. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Technical Report No. 2006-07.

Eyeson-Annan, M., Peterken, C., Brown, B., & Atchison, D. A. 1996. Visual and vestibular components of motion sickness. Aviation, Space, and Environmental Medicine. 67(10): 955-962.

Fischer, P. R. 1998. Travel with infants and children. Infectious Disease Clinician North America. 12(2): 355-368.

Furusho, J., Suzuki, M., Tazaki, I., Satoh, H., Yamaguchi, K., Iikura, Y., Kumagai, K., Kubagawa, T., & Hara, T. 2002. A comparison survey of seizures and other symptoms of Pokemon Phenomenon. Pediatric Neurology. 27(5): 350-355.

Golding, J. F. 2006. Predicting individual differences in motion sickness susceptibility by questionnaire. Personality and Individual Differences. 41: 237-248.

Golding, J. F., & Stott, J. R. R. 1997. Objective and subjective time course of recovery from motion sickness assessed by repeated motion challenges. Journal of Vestibular Research. 7(6): 421-428.

Gordon, C. R., Ben-Aryeh, H., Spitzer, O., Doweck, I., Gonen, A., Melamed, Y., & Shupak, A. 1994. Seasickness susceptibility, personality factors and salivation. Aviation, Space, and Environmental Medicine. 65(7): 610-614.

Graybiel, A., Kennedy, R. S., Knoblock, E. C., Guedry, F. E., Mertz, W., McLeod, M. E., et al. 1965. Effects of exposure to a rotating environment (10 rpm) on four aviators for a period of twelve days. Aerospace Medicine. 36: 733-754.

Graybiel, A., & Knepton, J. 1976. Sopite syndrome: A sometimes sole manifestation of motion sickness. Aviation, Space, and Environmental Medicine. 47: 873-882.

Griffin, M. J., & Mills, K. L. 2002a. Effect of frequency and direction of horizontal oscillation on motion sickness. Aviation, Space, and Environmental Medicine. 73(6): 537-543.

Griffin, M. J., & Mills, K. L. 2002b. Effect of magnitude and direction of horizontal oscillation on motion sickness. Aviation, Space, and Environmental Medicine. 73(7): 640-646.

Han, Y.H., Kumar, A.N., Somers, J.T., Reschke, M.F., & Leigh, R.J. 2005. Effects of retinal image slip on modulation of visual vestibule-ocular reflex during near viewing. Annals of the New York Academy of Sciences. 1039: 463-465.

Harm, D. L. 2002. Motion sickness neurophysiology, physiological correlates, and treatment. In K. M. Stanney (Ed.) Handbook of Virtual Environments. Mahwah, NJ: Lawrence Erlbaum Associates. pp. 637-662.

Harrison, Y., & Horne, J. A. 2000. The impact of sleep deprivation on decision making: A review. Journal of Experimental Psychology: Applied. 6(3): 236-249.

Headquarters, Department of the Army. 2000. Aeromedical training for flight personnel. Field Manual 3-04.301 (1-301): 9-13-9-14.

Heinle, T. 2001. Spatial disorientation. Wright-Patterson Air Force Base, OH: In Gateway, Human Systems Information Analysis Center. Volume 12.

Howarth, H. V. C., & Griffin, M. J. 2003. Effect of roll oscillation frequency on motion sickness. Aviation, Space, and Environmental Medicine. 74(4): 326-331.

Johnson, D. M. 2005. Introduction to and review of simulator sickness research. Arlington, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. ARI Research Report 1832.

Kellogg, R. S., Kennedy, R. S., & Graybiel, A. 1965. Motion sickness symptomatology of labyrinthine defective and normal subjects during zero gravity maneuvers. Aerospace Medicine. 36: 315-318.

Lawson, B. D., Kass, S. J., Kennedy, R. S., Muth, E. R., & Smith, S. A. 2003. Vestibular stimuli may degrade situation awareness even when overt spatial disorientation is not experienced. Proceedings of the Human Factors and Medicine Panel Symposium, "Spatial disorientation in military vehicles: causes, consequences, and cures". La Coruna, Spain: pp. 43-1-43-22.

Lawson, B. D., McGee, H. A., Castaneda, M. A., Golding, J. F., Kass, S. J., & McGrath, C. M. 2009. Evaluation of several common anti-motion sickness medications and recommendations concerning their potential usefulness during special operations. Pensacola, FL: Naval Aerospace Medicine Research Laboratory. NAMRL Technical Report 09-15.

Lawther, A., & Griffin, M. J. 1988. A survey of the occurrence of motion sickness amongst passengers at sea. Aviation, Space, and Environmental Medicine. 59: 399-406.

Lim, J., & Dinges, D. F. 2008. Sleep deprivation and vigilant attention. Annals of the New York Academy of Sciences. 1129: 305-322.

Melvill-Jones, G., & Mandl, G. 1981. Motion sickness due to vision reversal: Its absence in stroboscopic light. Annals New York Academy of Sciences. 374: 303-311.

National Society for Epilepsy. n.d. Information on epilepsy: Photosensitive epilepsy. Retrieved 4 May 07 from http://www.epilepsynse.org.uk/pages/info/leaflets/photo.cfm and http://www.epilepsynse.org.uk/pages/info/glossary/index.cfm#F.

Physicians' Desk Reference. 2001. Montvale, NJ: Medical Economics Company, Inc. pp 1894-1896. Meclizine: 2469; Phenergan: 3419-20; Transdermal Scopolamine: 2138-2140.

Rash, C. E. 2004. Awareness of causes and symptoms of flicker vertigo can limit ill effects. Flight Safety Foundation - Human Factors and Aviation Medicine: 51(2).

Reschke, M. F., Krnavek, J. M., Somers, J. T., Ford, G., Hwang, E. J., Leigh, R. J., & Estrada, A. 2007. Stroboscopic vision as a treatment for retinal slip induced motion sickness. Paper presented at the First International Symposium on Visually Induced Motion Sickness, Fatigue, and Photosensitive Epileptic Seizures conference. Hong Kong. pp. 10-11.

Reschke, M. F., Somers, J. T., & Ford, G. 2006. Stroboscopic vision as a treatment for motion sickness: Strobe lighting vs. shutter glasses. Aviation, Space, and Environmental Medicine. 77(1): 2-7.

Rickert, D. 2000. C41 Mobile Operational Prototype (CMOP). User Jury 8 Summary Report, September 19-21, 2000. Woodbridge, VA: General Dynamics Amphibious Systems.

Stern, R. M. 2002. The psychophysiology of nausea. Acta Biologica. 53(4): 589-599.

Stroboscopic goggles for reduction of motion sickness. 2005. Retrieved 8 Feb 08 from http://www.techbriefs.com/component/content/article/236.

Thorne, D. R., Johnson, D. E., Redmond, D. P., Sing, H. C., & Belenky, G. 2005. The Walter Reed palm-held psychomotor vigilance test. Behavior Research Methods. 37: 111-118.

Van Dongen H. P. A., Belenky, G., & Krueger, J. M. 2010. Investigating the temporal dynamics and underlying mechanisms of cognitive fatigue. In Ackerman PL (Ed.), Cognitive Fatigue. Washington, D.C.: American Psychological Association: pp. 127–147.

Webb, C. M., Estrada, A., Athy, J. R., Rath, E., et al. 2009. Motion sickness prevention by stroboscopic illumination during simulated military transport. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report Number 2009-14.

Wick, R.L. 1982. No flicker vertigo. Letter to the editor. Business/Commercial Aviation. 51(16).

Yen P. S., Fleur, D., Golding, J. F., & Gresty, M. A. 2003. Suppression of sickness by controlled breathing during mildly nauseogenic motion. Aviation, Space, and Environmental Medicine. 74(9): 998-1002.

Young, H. Y., Chiang, C. T., Huang, Y. L., Pan, F. P., & Chen, G. L. 2002. Analytical and stability studies of ginger preparations. Journal of Food and Drug Analysis. 10(3): 149-153.

Appendix A.

Motion Sickness Susceptibility Questionnaire.

Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short)

1. Please State Your **Age** ..... Years. *2.* Please State Your Sex (tick box) **Male** [1] **Female** [2]

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. Sickness here means feeling queasy or nauseated or actually vomiting.

Your CHILDHOOD Experience Only (before 12 years of age), for each of the following types of transport or entertainment please indicate:

3. **As a CHILD (before age 12),** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Your Experience over the LAST 10 YEARS (approximately), for each of the following types of transport or entertainment please indicate:

4. **Over the LAST 10 YEARS,** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Appendix B.

Flight profile.

Man #	Maneuver Description	Headings	Altitude (FEET)	Airspeed
Notes:	Ensure blackout curtains are in place.			
	Turn SAS – OFF before takeoff.			
1	Straight Climb (Upwind) – Allow acft to PR&Y with inputs	Hdg 030 or 210	0’ AGL -> 1000’ MSL	0 -> 80
2	LCT (450 degrees to Crosswind) – Vary climb rate	Hdg 030 or 210 -> Hdg 300 or 120	1000’ MSL -> 1500’ MSL	80
3	RDT (360 degrees) – Vary descent rate	Hdg 300 or 120 -> Hdg 300 or 120	1500’ MSL -> 1000’ MSL	80
4	LDT (450 degrees to Downwind) – Vary descent rate	Hdg 300 or 120 -> Hdg 210 or 030	1000’ MSL -> 500’ MSL	80
5	RCT (360 degrees) – Vary climb rate	Hdg 210 or 030 -> Hdg 210 or 030	500’ MSL -> 1500’ MSL	80
6	Straight Flight (Downwind) – Allow acft to PR&Y with inputs	Hdg 030 or 210	1500’ MSL	80
7	LDT (450 degrees to Base) – Vary descent rate	Hdg 210 or 030 -> Hdg 120 or 300	1500’ MSL -> 1000’ MSL	80
8	RDT (270 degrees to Final) – Vary descent rate	Hdg 120 or 300 -> Hdg 030 to 210	1000’ MSL -> 500’ MSL	80
9	Straight Descent to touchdown – Allow acft to PR&Y with inputs	Hdg 030 or 210	500’ MSL -> 0’ AGL	80 -> 0

Note: Repeat two times.

Flight Profile Glossary

AGL – Above ground level. Hdg – heading. LCT – Left climbing turn. LDT – Left descending turn. MSL – Mean sea level. PR&Y – Pitch, roll, and yaw. RCT – Right climbing turn. RDT – Right descending turn. SAS – Stability Augmentation System.

Appendix C.

Motion Sickness Questionnaire.

Participant Number_____

For each symptom, please circle the rating that applies to you **RIGHT NOW**.

	0	1	2	3
General discomfort	None	Slight	Moderate	Severe
Fatigue	None	Slight	Moderate	Severe
Boredom	None	Slight	Moderate	Severe
Drowsiness	None	Slight	Moderate	Severe
Headache	None	Slight	Moderate	Severe
Eye strain	None	Slight	Moderate	Severe
Difficulty focusing	None	Slight	Moderate	Severe
Increased salivation	None	Slight	Moderate	Severe
Decreased salivation	None	Slight	Moderate	Severe
*Sweating	None	Slight	Moderate	Severe
Nausea	None	Slight	Moderate	Severe
Difficulty concentrating	None	Slight	Moderate	Severe
Mental depression	No	Yes		
“Fullness of the head”	No	Yes		
Blurred vision	No	Yes		
Dizziness w/ eyes open	No	Yes		
Dizziness w/ eyes closed	No	Yes		
Vertigo	No	Yes		
**Visual flashbacks	No	Yes		
Faintness	No	Yes		
Awareness of breathing	No	Yes		
***Stomach awareness	No	Yes		
Loss of appetite	No	Yes		
Increased appetite	No	Yes		
Desire to move bowels	No	Yes		
Confusion	No	Yes		
Burping	No	Yes		
Vomiting	No	Yes		

OTHER: Please Specify

_____

_____

_____

* Sweating “cold sweats” due to discomfort, not due to physical exertion

**Visual flashback- illusion of movement or false sensation similar to aircraft dynamics when not in a simulator or aircraft

***Stomach awareness-used to indicate a feeling of discomfort just short of nausea

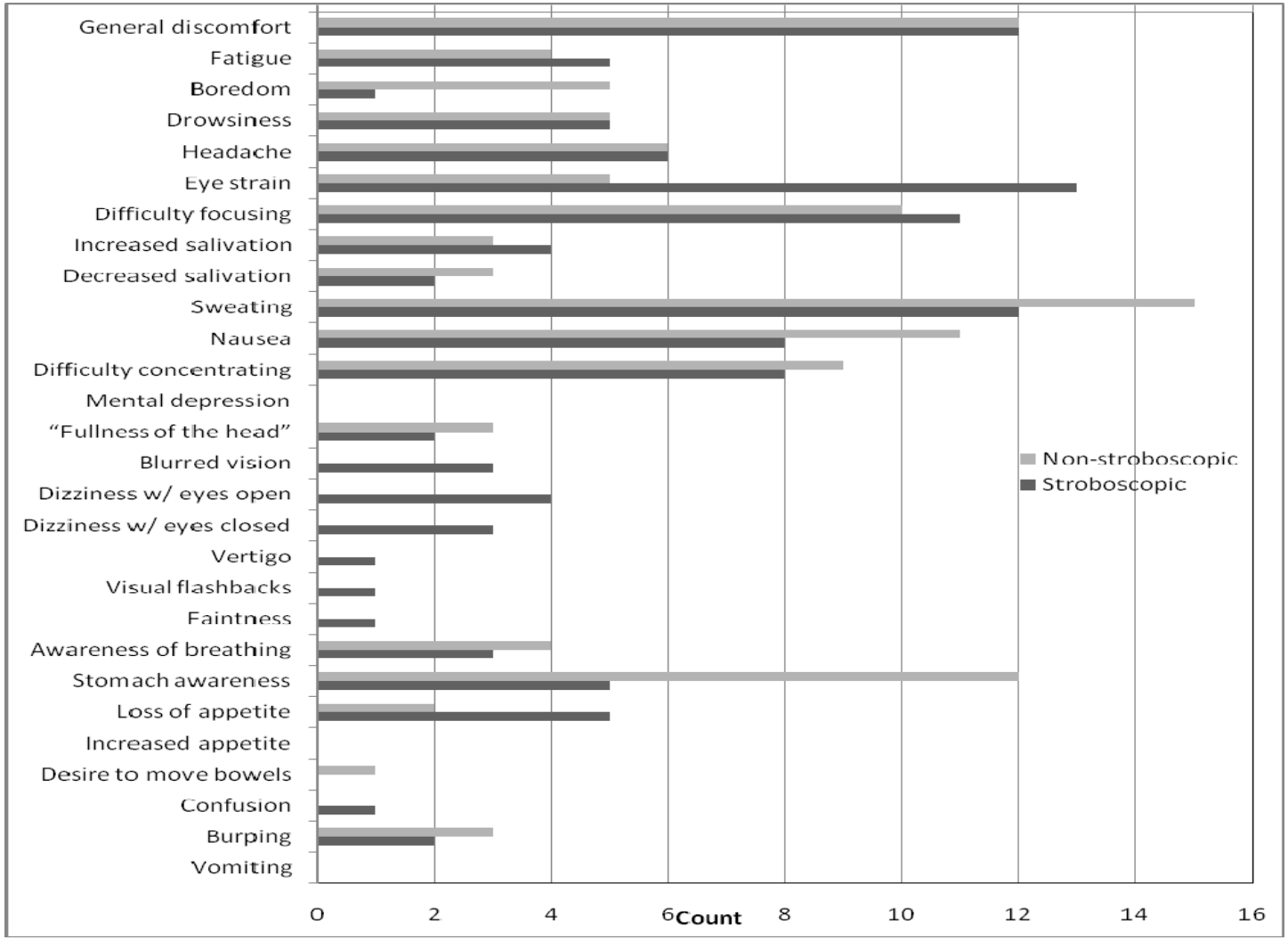
Appendix D.

Order of assessment battery.

Group	Order of assessment battery
1	1.TW
	2. EST
	3. RVP
	4. PVT
2	1. TW
	2. RVP
	3. PVT
	4. EST
3	1. PVT
	2. EST
	3. TW
	4. RVP
4	1. RVP
	2. EST
	3. PVT
	4. TW
5	1. EST
	2. RVP
	3. PVT
	4. TW

Appendix E.

MSQ Frequency data.



Appendix F.

Pairwise comparisions for EST data.

Position	Effect	Measure	Comparison		*p*
Prone supported	Distance	rt	50	100	.157
				150	.260
				200	.839
				250	.021
				300	.065
			100	150	.861
				200	.437
				250	.022
				300	.008
			150	200	.285
				250	.014
				300	.064
			200	250	.065
				300	.049
			250	300	.927
Prone supported	Distance	radius	50	100	.373
				150	.009
				200	.819
				250	.057
				300	.051
			100	150	.009
				200	.589
				250	.081
				300	.462
			150	200	.008
				250	.009
				300	.009
			200	250	.027
				300	.263
			250	300	.727

Position	Effect	Measure	Comparison		*p*
Prone supported	Distance	RMS	50	100	.031
				150	.017
				200	.669
				250	.039
				300	.520
			100	150	.020
				200	.475
				250	.218
				300	.927
			150	200	.020
				250	.022
				300	.022
			200	250	.018
				300	.553
			250	300	.411
Kneeling	Distance	RMS	50	100	.041
				150	.040
			100	150	.047

Department of the Army
U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama, 36362-0577
www.usaarl.army.mil

U.S. Army Medical Research and Materiel Command